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2. Patent application number *(The Patent Office will fill in this part)*	0327772.0
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	MBDA UK Limited Six Hills Way Stevenage, Hertfordshire SG1 2DA - 1 DEC 2003
Patents ADP number *(if you know it)*	08339350001
If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4. Title of the invention	IMPROVEMENTS IN OR RELATING TO AN ELECTRON GUN AND AN ELECTRON BEAM WINDOW THEREFOR
5. Name of your agent *(if you have one)*	
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Patents ADP number *(if you know it)*	07914674002
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Request for preliminary examination and search *(Patents Form 9/77)*	1
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Signature Malcolm EDIS Date 28/11/03

12. Name and daytime telephone number of person to contact in the United Kingdom Jeremy Goddin 01252 384625

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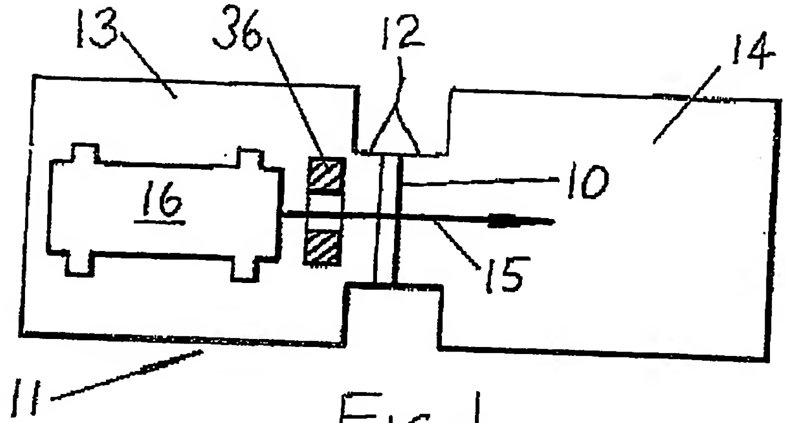


FIG. 1

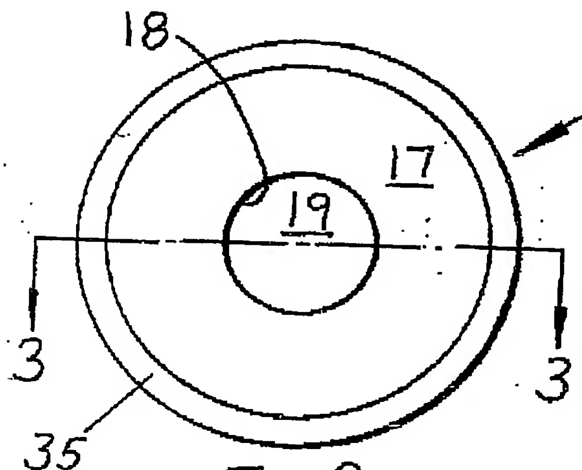


FIG. 2

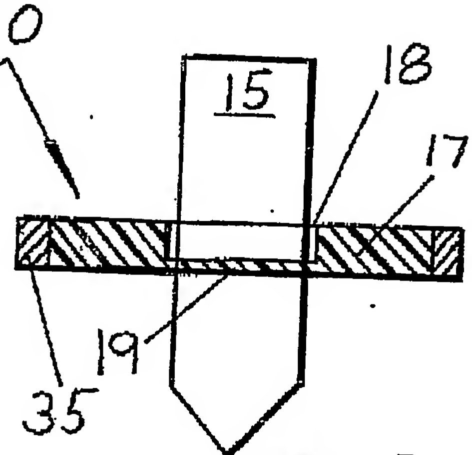


FIG. 3

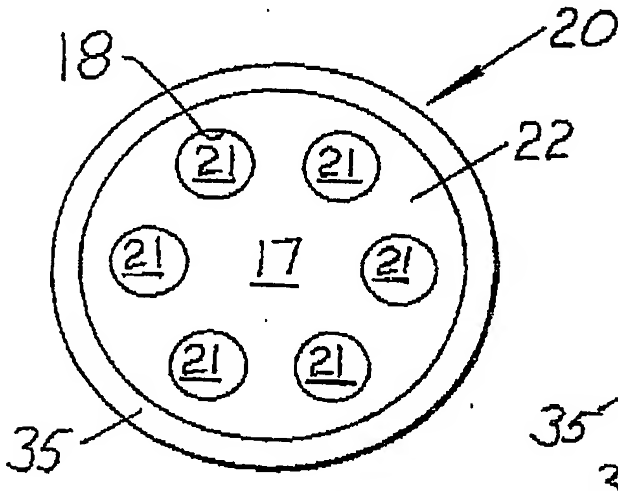


FIG. 4

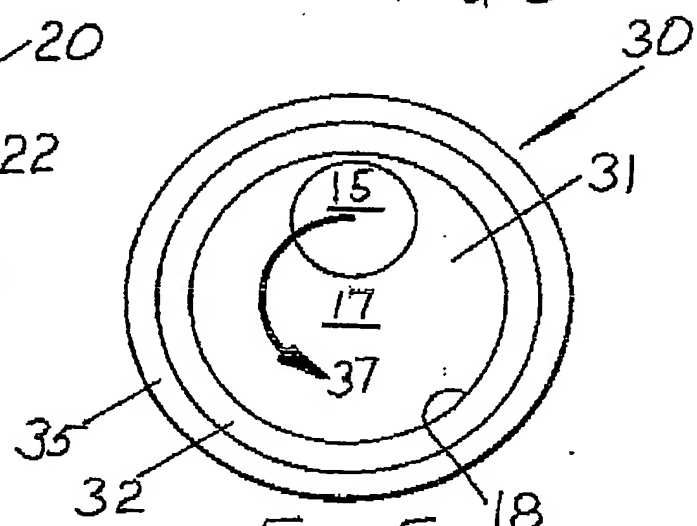
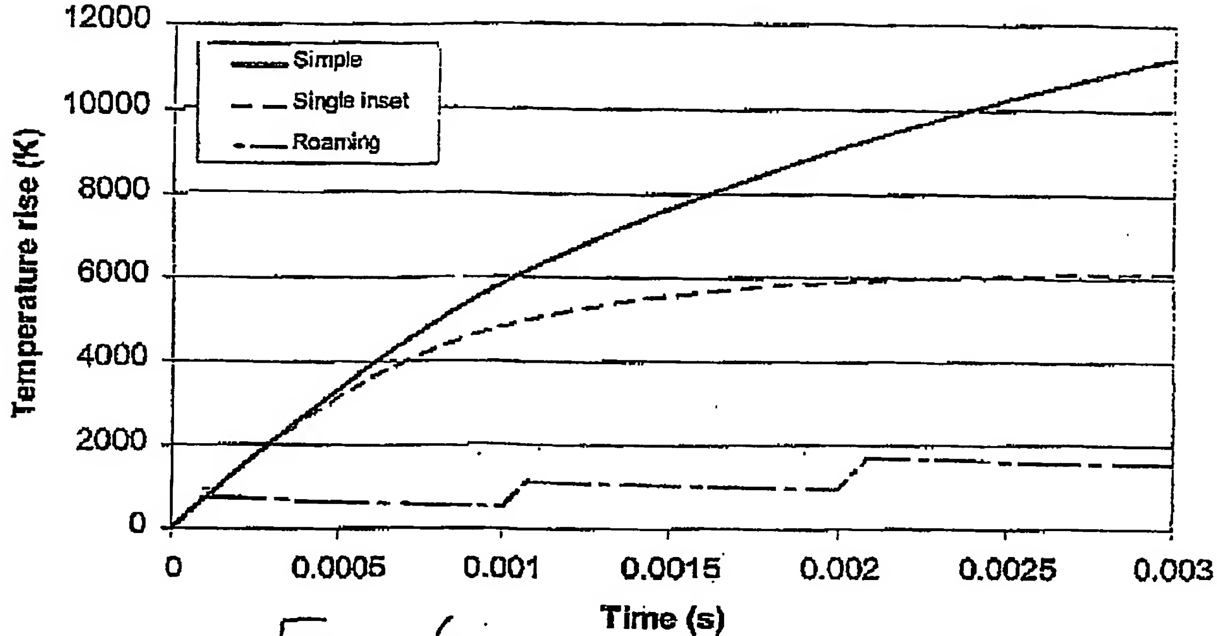
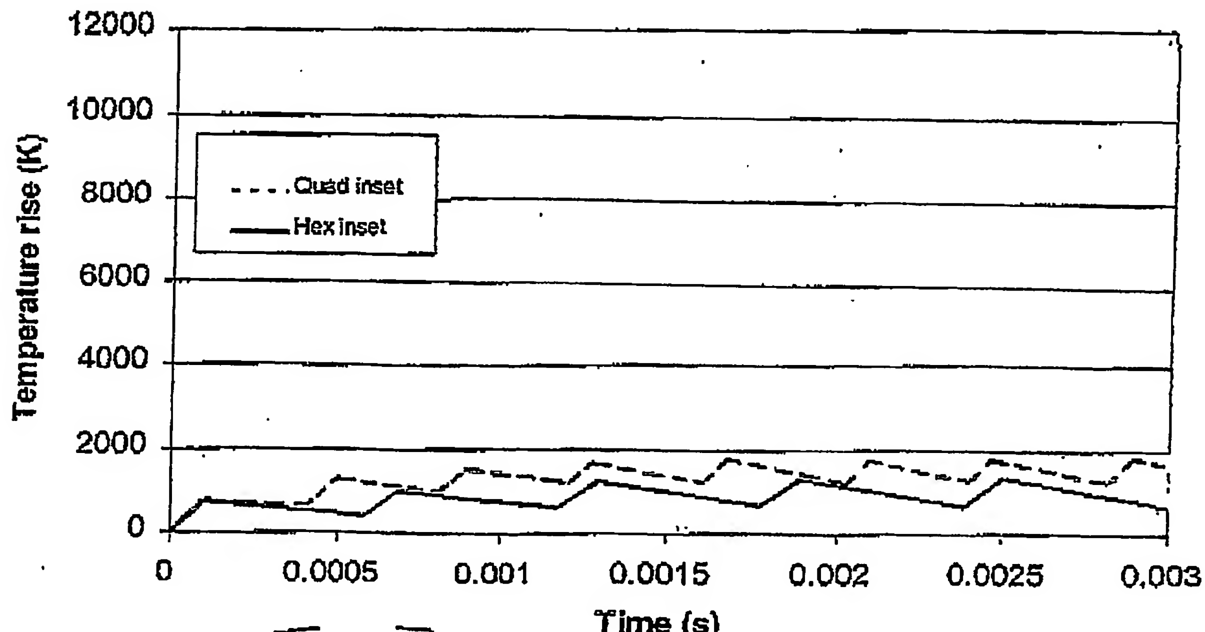


FIG. 5



Simple
Single inset
Roaming
Temperature rise (K)
12000
10000
8000
6000
4000
2000
0
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
Time (s)

FIG. 6



Quad inset
Hex inset
Temperature rise (K)
12000
10000
8000
6000
4000
2000
0
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
Time (s)

FIG. 7

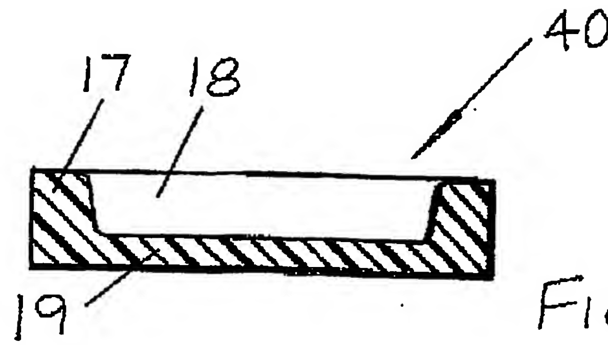


FIG.8

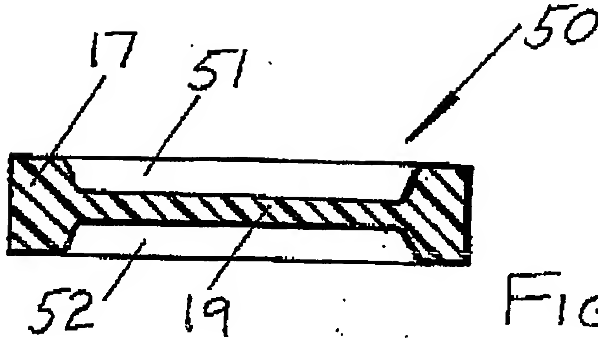


FIG.9

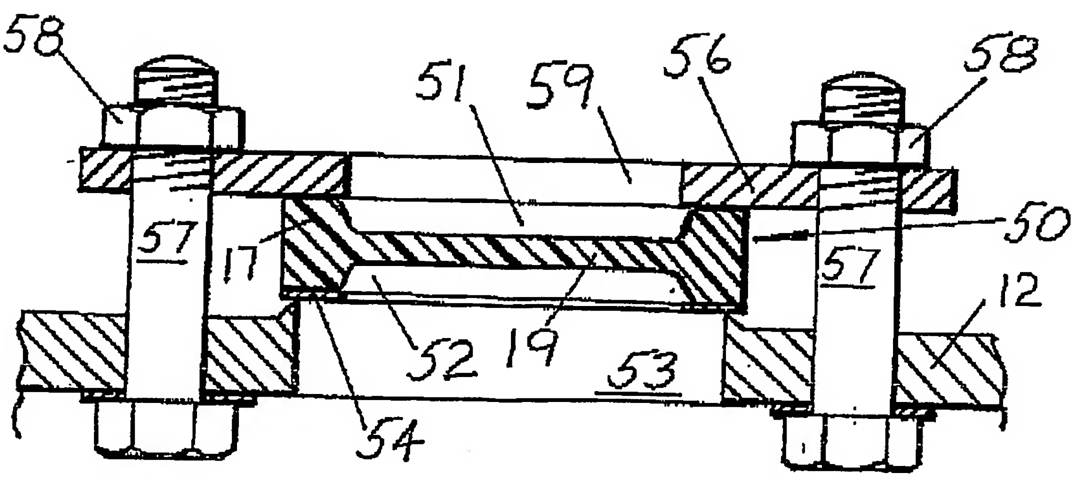


FIG.10

DUPLICATE

IMPROVEMENTS IN OR RELATING TO AN ELECTRON GUN AND AN ELECTRON BEAM WINDOW THEREFOR

This invention relates to a window for use in an electron gun, and to an electron gun provided with such a window.

Electron beams are useful in several applications including, for instance, electron beam welding, materials processing, and plasma generation. An electron gun is used to produce such electron beams by accelerating electrons to high velocity whereby the electrons have a high kinetic energy. Such acceleration is essentially carried out in a high-vacuum chamber, typically of 1 x 10^{-6} mBar (millibar).

When the electron beam is to be used in a higher pressure environment, it is necessary to provide the high vacuum chamber with an electron beam window thereby permitting the accelerated electrons to pass from the high vacuum chamber into the higher pressure environment.

Such electron beam window therefore constitutes an interface between the high vacuum chamber and the higher pressure environment and must meet the following criteria: -

1. Sufficient strength to withstand the pressure differential.
2. Allow the passage of the accelerated electrons.
3. Have minimal electron beam absorption.
4. Be able to withstand the temperature rise occurring during transmission of the electron beam

An electron passing through a thin layer of material loses energy by collisional scattering processes in accordance with Bethe's equation:

$$\frac{dE}{dx} \propto \frac{Z\rho}{A} \ln\left(\frac{E}{I}\right)$$

This states that the rate of energy loss $\frac{dE}{dx}$ is proportional to the atomic number Z and the density ρ of the material the electrons pass through, is inversely proportional to the atomic mass A, and is proportional to the log of the ratio of the electron energy E to the atomic ionisation energy I.

In order to minimise energy loss, the most suitable materials for forming an electron beam window have hitherto been chosen from those having a low density and consequently low electron energy absorption. It is also recognised that the material must also have good mechanical properties so that the window can be as thin as possible.

The energy absorbed by the electron beam window causes its temperature to increase all the time that the electron beam is being transmitted. For this reason the thermal characteristics of the material forming the electron beam window are preferably a high thermal conductivity K so that heat will be conducted away as quickly as possible, also a high specific heat capacity so that the temperature rise for a given absorbed energy will be relatively low, and a high maximum service temperature to extend the time during which the electron beam may be transmitted without causing thermal damage.

Conventionally an aluminium beryllium alloy is employed for forming electron beam windows and typically has the following properties: -

Density, ρ	2122/kg/m^3
Thermal conductivity, K	246 W/m/K
Specific heat capacity	1675 J/kg/K
Maximum service temperature	610 K
Tensile strength	447MPa

The tensile strength of a typical aluminium beryllium alloy enables a 10mm pane to be formed from a 36 micron foil to withstand a pressure differential of one atmosphere. At this foil thickness approximately 15% of the energy of a 125 KeV electron beam will be absorbed by the pane and the thermal loading associated with this rate of absorption limits the use of an

aluminium beryllium pane to either a pulsed electron beam system, or a very low current continuous electron beam system.

The present Invention is concemed with improving the performance of an electron beam window, and an electron gun using such an improved window.

According to one aspect of the invention, an electron beam window has a diamond pane. Until very recently the choice of an exotic material, such as a diamond, would have been out of the question due to the inherent cost. Although its specific heat capacity typically 400J/Kg/K is only one quarter of that of aluminium beryllium alloy, it has a higher density of 3,580 Kg/m^3 and very much higher thermal conductivity (2400 W/m/K), maximum service temperature (2000 K), and tensile strength (2930 MPa). Due to the exceptional mechanical strength and ability to withstand extremely high temperatures, a 10mm pane can be formed with a thickness of only 3.1 microns to withstand a pressure differential of one atmosphere. This reduction in thickness leads to an absorption of only 2% of the energy of a 125 KeV electron beam.. Furthermore the much higher thermal conductivity enables this heat to be conducted away from the pane at a much higher rate. The higher rate of thermal conduction, combined with the extremely high maximum temperature, enables the electron beam to be transmitted without interruption for a very much longer period than has hitherto been possible.

The diamond pane is preferably formed by chemical vapour deposition. This is very much less costly than using natural diamond. Various methods are known for the synthetic production and shaping of diamond. For instance, US Patents 5,264,071 and 5,349,922 teach the production of monolithic diamond sheet by passing a mixture of hydrogen and a hydrocarbon at high temperature over a cooled substrate on which diamond is deposited.

According to the invention the diamond pane is preferably formed integral with a relatively thicker peripheral rim. This diamond rim serves as a thermal transport substrate which, due to its high thermal conductivity and integral formation with the pane, provides exceptionally high transfer of thermal energy away from the pane. The thickness of the peripheral rim is therefore

selected to be sufficient to dissipate heat generated in the pane by the passage of an electron beam. If desired, the rim may be connected to a heat sink which is preferably shrunk onto the rim and is diffusion bonded to it.

According to the invention the thickness of the pane is selected to be sufficient to withstand a predetermined pressure differential across the pane. The thickness of the pane may typically be between 25 microns and 5 microns and is preferably about 10 microns.

Although the diamond pane may be a single crystal it may be polycrystalline. Use of polycrystalline diamond provides a substantial improvement over aluminium beryllium but, where cost permits, single crystal diamond provides a very much larger improvement.

The peripheral rim may be mounted in a support frame which may constitute the heat sink.

If desired a plurality of diamond panes may be mounted in the support frame. Alternatively and preferably a plurality of diamond panes may be formed integral with a single peripheral rim.

According to another aspect of the invention an electron gun is arranged to produce an electron beam within a vacuum chamber and to direct the electron beam, through an electron beam window having a diamond pane, into a region of higher pressure. In the case where the electron beam window comprises a diamond pane surrounded by a relatively thicker integral peripheral rim, the peripheral rim is preferably supported by structure within the electron gun to withstand the force applied to the diamond pane by the pressure difference between the vacuum chamber and the region of higher pressure and also to dissipate heat, generated by the passage of the electron beam through the pane, to the structure.

The pane may have a dimension, transverse to the direction of the electron beam, that is more than twice the transverse dimension of the electron beam, and a scanning means is provided to cause continuous relative movement between the electron beam and the pane whereby the electron beam will be transmitted through changing areas of the pane. The dimension

may be the diameter of a circular area of the pane, and the scanning means may cause the electron beam to orbit around this circular area.

Alternatively the scanning means may be arranged to cause the electron beam to perform a raster scan across the pane.

Alternatively a plurality of the diamond panes may have a common peripheral rim supported by the structure, and a scanning means is arranged to cause relative indexing between the electron beam and the plurality of diamond panes whereby the electron beam will be transmitted for a limited time by each diamond pane in sequence.

The scanning means is preferably magnetic and operable to move the electron beam relative to the electron beam window.

The invention will now be described, by way of example only, with reference to the accompanying diagrams in which: -

Figure 1 is a diagrammatic longitudinal section through an electron gun illustrating the position of its electron beam window;

Figure 2 is an axial view of one form of electron beam window as taught by the present invention;

Figure 3 is a diametrical section taken along the line 3-3 in Figure 2;

Figure 4 is a an axial view of another form of electron beam window as taught by the present invention;

Figure 5 is an axial view of a further form of electron beam window as taught by the present invention;

Figure 6 is a graph of computed temperature rise against time showing the improved performance achieved by the electron beam windows illustrated in Figures 2 and 5;

Figure 7 is a graph similar to Figure 6 but showing the improved performance of an electron beam window having 6 panes as shown in Figure 4, and also of a similar electron beam window provided with only four panes;

Figure 8 is a diametrical section through another form of electron beam window as taught by the present invention;

Figure 9 illustrates a modification of the electron beam window illustrated in Figure 8, and

Figure 10 illustrates the mounting of the electron beam window shown in Figure 9 to a support structure within an electron gun.

With reference to Figure 1, an electron beam window 10 is positioned inside a typical electron gun 11 with its periphery supported from a structure 12 which connects a vacuum chamber 13 to a chamber 14 that is to receive an electron beam 15 from an electron beam generator 16. The vacuum chamber 13 is evacuated to generate a vacuum of typically 10^{-6} mb. The chamber 14 defines a region of higher pressure, as is well known in the art, the electron beam window 10 serving as a physical barrier to preserve the pressure difference between the chambers 13 and 14. Consequently, the electron beam window 10 must withstand a force equal to its cross sectional area times the pressure difference between chambers 13 and 14, this force being transmitted to the structure 12.

With reference to Figures 2 and 3, the electron beam window 10 is formed from a cylindrical disc 17 of polycrystalline diamond manufactured by chemcial vapour deposition or by any other convenient process. The cylindrical disc 17 is approximately 1mm thick and has a central cylindrical depression 18 formed by ion beam etching. The formation of the cylindrical depression 18 is carefully controlled so that a 10 micron thick pane 19 is left having a diameter of about 10mm to match the diameter of the electron beam 15. In this manner the pane 19 is formed integral with the thicker annular portion of the cylindrical disc 17 which constitutes a peripheral rim serving as a heat sink. This integral construction ensures excellent conductivity to dissipate the heat generated by the passage of the electron beam 15 through the pane 19. By using this single inset pane 19, the thermal loading capability of the electron beam window 10 is improved because the thickness of the pane 19 is minimised whilst the remainder of the cylindrical disc 17 provides increased thermal conduction. This design is most efficient when the diameter of the pane 19 equals the diameter of the electron beam 15.

Figure 4 illustrates an alternative electron beam window 20 in which the cylindrical disc 17 of polycrystalline diamond has been ion beamed etched to

define six separate panes 21 of equal thickness and diameter, of the disc 17 constituting a common peripheral rim 22 serving as a heat sink.

Figure 5 illustrates another electron beam window 30 in which the cylindrical disc 17 of polycrystalline diamond has been ion beam etched to define a single pane 31 having a diameter that is more than twice the transverse dimension of the electron beam 15. In this manner, the single pane 31 is surrounded by a much thicker integral peripheral rim 32.

Although the thicker portion of the cylindrical discs 17 shown in Figures 2 to 5 serves as a heat sink, the overall thermal capacity can be increased by fitting a heat sink ring 35 to the outer rim of the cylindrical disc 17 as shown in Figures 2 and 3, or to the outer cylindrical surface of the peripheral rims 22 and 32 as respectively shown in Figures 4 and 5. Such heat sink ring 35 is preferably made as a copper ring shrunk onto the disc 17 and diffusion bonded to ensure excellent thermal conduction. If desired, a heat sink could alternatively or additionally be secured to any other surface of the discs 17 provided that it did not obscure the pane 19 or 31, or the panes 21. Instead of being made of copper, the heat sink 35 could be formed of aluminium or any other appropriate material.

With the electron beam window 10 described with reference to Figures 1 to 3, the electron beam 15 is simply directed through the pane 19 and the energy absorbed by the pane 19 is conducted radially outwardly into the integral thicker portion of the cylindrical disc 17, and then into the heat sink fing 35. The dotted graph in Figure 6 shows the calculated temperature rise in degrees Kelvin plotted against time, for an electron beam of 31.25 kw passing through a 10μm pane of 5mm diameter formed integral with a cylindrical disc 17 that is 1mm thick and has a diameter of 32mm. The full-line graph in Figure 6 shows the calculated characteristic for a nominal pane of the same thickness but with a diameter of 32mm. Consequently the vertical gap, between the full-line and dotted line graphs in Figure 6, indicates the extent of the benefit gained by the increased thickness of the outer annular portion of the cylindrical disc 17. However, a comparable characteristic for a conventional aluminium beryllium alloy would be very much steeper than the full-line graph in Figure 6. It will therefore be understood that the provision of a simple diamond pane without a

thicker peripheral rim achieves a substantial improvement over a similar pane made of aluminium beryllium alloy, and also that the provision of the thicker integral peripheral rim achieves a further substantial improvement. However, in both cases, the graphs very quickly exceed the 2000k maximum service temperature of diamond and show that these constructions are only useful for the transmission of an electron beam for a very short time, or of substantially lower power.

A further significant improvement is achieved by the designs of electron beam windows 20 and 30 respectively illustrated in Figures 4 and 5, together with the modification of the electron gun 10 to provide relative movement between the electron beam 15 and the windows 20 and 30. This relative movement is achieved by a scanning means 36 positioned within the vacuum chamber 13 as indicated generally in Figure 1.

The use of the electron beam window 30 of Figure 5 requires the electron beam 15 to be moved continuously relative to the pane 31 by the scanning means 36. This design necessitates the use of an oversized pane 31 but reduces the thermal loading whilst increasing thermal dissipation. In Figure 5, this relative movement is indicated by arrow 37 and is such that the electron beam 15 is continuously transmitted through changing areas of the pane 31. As shown, the diameter of the pane 31 is more than twice that of the electron beam 15 so that the scanning means 36 will sweep the electron beam 15 progressively over fresh areas of the pane 31 until it starts to overlap its original location which, in the meantime will have been cooled by conduction through the integral peripheral rim 32 and, if fitted, into the heat sink ring 35. The chain-dotted graph in Figure 6 shows the calculated temperature rise in the pane 31 caused by an electron beam of the same power, the pane 31 being 10mm in thickness with a diameter of 17.5 mm within an integral peripheral rim 32 of 32mm diameter, the scanning rate being 1KHz. It is very noticeable that the chain-dotted graph remains, at all times shown, below the 2000°K maximum service temperature of diamond, and that the steps in the chain-dotted graph correspond with completion of each rotary cycle of the electron beam 15 around the pane 31. The temperature is computed at the centre of the window 31. By appropriately balancing the speed of relative rotation and the proportions of the

integral peripheral rim 32 (and the conductivity of the heat sink ring 35, if fitted) with the power of the electron beam 15, it is clear that continuous transmission of an electron beam 15 in excess of 30 kw can be achieved. Also that a substantially higher power electron beam 15 could be transmitted intermittently. The design of electron beam window 20 accommodates electron beam 15 of differing diameter.

If desired, different scanning patterns may be achieved using the scanning means 36, for instance raster-scanning. In the latter case the pane 31 could be of a different shape .

The electron beam window 20 shown in Figure 4 (hereinafter called the "Hex inset") has its six panes 21 scanned by using the scanning means 36 to index the electron beam 15 sequentially through each pane 21. The electron beam 15 is therefore transmitted through each pane 21 until its temperature approaches a safe level below the maximum service temperature, and is then quickly indexed to the next pane 21. The full-line graph in Figure 7 shows the calculated temperature rise in degrees Kelvin, plotted against time, for an electron beam 15 of the same power passing sequentially through the six 10μm panes 21 of a Hex inset electron beam window 20, each pane 21 being 6.5mm in diameter with a common peripheral rim 22 having a diameter of 32mm, the dwell time on each of the panes 21 being 100μs. From this full-line graph it will be noted that the steps correspond with the movement of the electron beam 15 across the material of the peripheral rim 22 whilst indexing between adjacent panes 21. During this movement a greater proportion of the energy of the electron beam 15 is lost in the thicker material of the peripheral rim. It is clearly beneficial either to minimise the indexing time, or to switch the electron beam 15 off whilst indexing is occurring.

The dotted graph in Figure 7 shows the calculated performance of another electron beam window, similar to the Hex inset but provided with only four panes of 4.5m diameter (hereinafter termed the "Quad inset"). It will be seen that, after the first relative rotation, the temperature profile of the Quad insset has stabilised comfortably below the 2000°K maximum service temperature.

Both the Hex inset and the Quad inset enable an electron beam to be transmitted almost continuously, that is as a continuous series of high efficiency transmissions interspersed either by very short transmission breaks of by very short intervals of lower efficiency transmission.

As well as the Hex inset and the Quad inset, the design of electron beam window illustrated in Figure 4 may be modified to have any number N of panes 21. This use of multiple panes 21 reduces the thermal load on each pane 21 because it will experience a thermal duty cycle of only $\frac{1}{N}$.

Figure 8 illustrated in greater detail the physical features of an electron beam window 40 comprising a cylindrical diamond disc 17 very similar to that already described and illustrated in Figures 2 and 3. The same reference numerals have been used to identify equivalent features and only the points of difference will be described. As will be seen from Figure 8, the central cylindrical depression 18 is etched by an ion beam to have gently rounded corners to avoid forming any stress raisers that could otherwise lead to cracking as the temperature varies. The cylindrical wall of the depression 18 is formed to be slightly frusto-conical.

Figure 9 illustrates another electron beam window 50 comprising a cylindrical diamond disc 17 which differs from that shown in Figure 8 only by the pane 19 being generated partly by a shallower central cylindrical depression 51 in the upper face (as seen in the drawing) of the disc 17, and partly by a shallow central cylindrical depression 52 in the lower face of the disc 17. In this manner both surfaces of the pane 19 are shaped by ion beam etching, or by any other appropriate process, and the pane 19 forms a web extending from the middle of the cylindrical disc 17, thereby providing balanced heat conduction for the upper and lower faces of the pane 19.

In Figure 10 the electron beam window 50, described with reference to Figure 9, is shown mounted to the structure 12 separating the vacuum chamber 13 from the chamber 14 as shown in Figure 1.

The structure 12 is a cast web of stainless steel formed with a cylindrical orifice 53 through which the electron beam will pass towards the pane 19. The electron beam window 50 has an annular copper sealing gasket 54 which is

tapped between the cylindrical disc 17 and an annular edge 55 formed integral with the structure 12.

In order to withstand the force created by the differential pressure across the electron beams window 50, a bracket 56 is slidably mounted on an array of stainless steel bolts 57 and is urged against the electron beam window 50 by corresponding locknuts 58. The bracket 56 is formed with a central aperture 59 to allow free passage of the electron beam. As the heads of the bolts 57 are within the vacuum chamber 13, they are provided with respective copper sealing washers as shown.

The various configurations of electron beam window 10, 20, 30, 40 and 50 described herein all offer significant advantages over the plain window configurations and traditional materials hitherto used.

These configurations fabricated from diamond allow increased electron beam current to be transmitted and permit improvements amounting to at least one order of magnitude. In particular they allow continuous electron beam transmission at high currents and higher electron beam transmission efficiency than hitherto.

As diamond is non-toxic and non-hazardous, it is an environmentally friendly alternative to the beryllium which is traditionally used despite the hazards to personnel during both manufacture and replacement of electron beam windows.

CLAIMS

1. An electron beam window having a diamond pane to transmit an electron beam.

2. An electron beam window, according to Claim 1, in which the diamond pane has been formed by chemical vapour deposition.

3. An electron beam window, according to Claim 1 or 2, in which the diamond pane is formed integral with a relatively thicker peripheral rim.

4. An electron beam window, according to Claim 3, in which the thickness of the peripheral rim is selected to be sufficient to dissipate heat generated in the pane by the passage of an electron beam.

5. An electron beam window, according to Claim 3 or 4, in which the rim is connected to a heat sink.

6. An electron beam window, according to Claim 5, in which the heat sink is shrunk onto the rim.

7. An electron beam window, according to Claim 5 or 6, in which the heat sink is diffusion bonded to the rim.

8. An electron beam window, according to any of Claims 3 to 7, in which the thickness of the pane is selected to be sufficient to withstand a predetermined pressure differential across the pane.

9. An electron beam window, according to any preceding claim, in which the thickness of the pane is between 25 microns and 5 microns.

10. An electron beam window, according to Claim 9, in which the thickness of the pane is about 10 microns.

11. An electron beam window, according to any preceding claim, in which the diamond pane is a single crystal.

12. An electron beam window, according to any of Claims 1 to 10, in which the diamond pane is polycrystalline.

13. An electron beam window, according to any of Claims 3 to 12, in which the peripheral rim is mounted in a support frame.

14. An electron beam window, according to Claim 8, in which a plurality of diamond panes is mounted in the support frame.

15. An electron beam window according to Claim 8, in which a plurality of diamond panes are formed integral with a single peripheral rim.

16. An electron beam window substantially as described herein with reference to the accompanying drawings.

17. An electron gun arranged to produce an electron beam within a vacuum chamber and to direct the electron beam, through an electron beam window in accordance with any preceding claim, into a region of higher pressure.

18. An electron gun, according to Claim 17 and in the case where the electron beam window comprises a pane surrounded by a relatively thicker peripheral rim, in which the peripheral rim is supported by structure within the electron gun to withstand the force applied to the diamond pane by the pressure difference between the vacuum chamber and the region of higher pressure and also to dissipate heat, generated by the passage of the electron beam through the pane, to the structure.

19. An electron gun, according to Claim 17 or 18, in which the pane has a dimension, transverse to the direction of the electron beam, that is more than twice the transverse dimension of the electron beam, and a scanning means is provided to cause continuous relative movement between the electron beam and the pane whereby the electron beam will be transmitted through changing areas of the pane.

20. An electron gun, according to Claim 19, in which the dimension is the diameter of a circular area of the pane, and the scanning means causes the electron beam to orbit around this circular area.

21. An electron gun, according to Claim 19, in which the scanning means is arranged to cause the electron beam to perform a raster scan across the pane.

22. An electron gun, according to Claim 18, in which a plurality of the diamond panes have a common peripheral rim supported by the structure, and a scanning means is arranged to cause relative indexing between the electron beam and the plurality of diamond panes whereby the electron beam will be transmitted for a limited time by each diamond pane in sequence.

23. An electron gun, according to any of Claims 19 to 22, in which the scanning means is magnetic and operable to move the electron beam relative to the electron beam window.

24. An electron gun constructed and arranged substantially as described herein with reference to the accompanying drawings.

ABSTRACT

IMPROVEMENTS IN OR RELATING TO AN ELECTRON GUN AND AN ELECTRON BEAM WINDOW THEREFOR

An electron beam window 30 is formed with a diamond pane 31 to transmit an electron beam 15. The pane 31 is formed in a cylindrical disc 17 of single crystal or of polycrystalline diamond such that the pane 31 is surrounded by a thicker integral peripheral rim 32 which conducts heat away from the pane 31. A heat sink ring 35 can be fitted to the outer cylindrical surface of the peripheral rim 32. The diameter of the pane 31 can be more than twice the diameter of the electron beam 15 so that performance is improved by scanning the electron beam 15 around the diamond pane 31 as indicated by arrow 37. The use of diamond pane reduces the electron beam energy converted to heat in the pane 31, the thicker peripheral rim 32 increases cooling of the pane 31, and the scanning movement 37 reduces the temperature rise of the pane 31.

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